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ECOP: Energy Conserving Postboxes in Postbox Delay Tolerant Networks

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Abstract

The Delay Tolerant Network (DTN) came as a saviour for heterogeneous networks marked by intermittent connectivity and low energy levels. By the introduction of the BUNDLE layer in addition to the TCP/IP layers, the DTN tries to achieve what the TCP/IP could not i.e. allow communication in challenged networks. The Postbox DTN is a type of DTN which has a persistent node known as Postbox which is always ON. All nodes have a direct connection to it and no other connection between nodes exist. Hence all communication is made via and by the Postbox just like the real world Postbox scenario. Apart from the novel concept of a 1 hop routing strategy, it is very easy to deploy. However its ease of use comes at a huge cost of energy usage by its always ON Postboxes. This work proposes a modified Postbox model which conserves energy without depreciating its performance. Simulation results confirm our hypothesis.

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Keywords:

Delay Tolerant Network (DTN) ; Postbox ; Energy Conservation ; Scheduled Power ON/OFF ; Time Sharing.

1. Introduction

With the evolving of technology at hyper speed, our life has changed too. The barriers are decreasing and the world is increasingly becoming a smaller place. The Delay Tolerant Network has played a very strong role in communicating the 'challenged' networks. Challenged networks are those which are challenged in one way or the other, like they have Long link delay, Absence of continuous end-to-end routing paths, Arbitrarily long periods of link disconnection, High error rates, Large bidirectional data-rate asymmetries etc. These are features which the existing TCP/IP cannot handle. Hence there was a need for some agent which would facilitate communication with and within these challenged networks. That is how DTN came into existence. The idea for DTN was actually penned by Internet pioneer Vinton Cerf when he was working on the InterPlanetary (IPN) project[1]. Though at first it was proposed for communication between planetary bodies, it was later scaled down for using it for communication in upcoming terrestrial networks which the TCP/IP failed to connect. Some such networks are Terrestrial civilian networks (connecting mobile wireless devices, including personal communicators, intelligent highways, and remote Earth outposts), Wireless Military Ad-Hoc battlefield networks (connecting troops, aircraft and satellites), Outer-space networks (such as the InterPlaNetary (IPN) Internet project), Sensor Networks (both on land and in water), War torn or Disaster struck areas (like a place hit by some natural calamity whose connection with the outside world has

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disrupted resulting into a network partition) etc. DTNs support interoperability of regional networks by handling enormous propagation delays between and within regional networks, and by translating between regional network communication characteristics. This is done by introducing in its layer structure a new layer called the Bundle layer on top of every region specific transport layer. It is in this layer that the 'delay' is 'tolerated'. A packet is considered to be delivered if and only if it reaches the destination within a certain time period, called time to live (TTL/ttl). Generally messages in DTNs have higher TTL value keeping into consideration the significant amount of time a particular message has to wait in intermediary buffers before reaching its final destination. Also nodes in DTN have more buffer size than usual. A node in an ordinary network buffers incoming messages in its memory chips whereas a node in a delay tolerant network stores messages in its hard disk. The reason for this is pretty evident as nodes in DTN have to store large number of messages for a much longer period of time than any node in a normal network periphery due to scarce and fluctuating connectivity among nodes in a DTN. Even then a node in practice cannot have infinite buffer size and thus the consideration of varying buffer sizes becomes momentous in measuring the effectiveness and feasibility of the algorithm.

As research in this domain is expanding, researchers are coming up with newer models in this field like HoP-DTN [2] and Postbox DTN [3]. These new models are beneficial for some special kind of networks like military battlefield networks etc. In this paper, we modify the classical Postbox model in an effort to decrease its energy consumption.

The rest of the paper is arranged as follows: we discuss the different models and their routing and energy saving schemes in the Previous Work section. After that we discuss our proposed approach followed by its performance evaluation and lastly we end with the conclusion.

2. Previous Work

Apart from the Vinton Cerf's architecture (and later modeled by Kevin Fall in[4]) of a DTN, quite a few architectures have been established for easier communication between varied, heterogeneous and special networks. Some of them are HoP-DTN, MIA-DTN and Postbox DTN. In HoP-DTN[5], there are extra nodes (custodian nodes which are used for message transfer only) dedicated to each node in the network. Once the custodian node is available, it will take a round trip from the source, traveling through the destination nodes, and return delivering the messages on its way and hence named homing pigeons inspired by the ancient messaging system. The custodian nodes are called pigeons and the nodes that they are dedicated to is called home node of that pigeon. Routing in HoP-DTN is a Traveling Salesman Problem which the creators solve by using the Ant Colony Optimization technique. Postbox DTN[3] introduces a centralized server (Postbox) inside each group of similar nodes known as clusters. Every communication is done via the postbox. It uses its own protocol for routing called the Postbox Based Routing Protocol which has a strict rule that all nodes must have a connection (might not be always up) with the postbox and the postbox itself must be up (ON) at all times. Monitor Incorporated Adaptive Delay Tolerant Network (MIA-DTN)[6,7] introduces some special nodes in the network known as *monitor* nodes. Monitor nodes are extra nodes dedicated to monitor/examine the other nodes present in the network and assign each of them a value called *PERM* based on their performance. They do not have the ability to create any message (hence consume very less energy due to their simple programming) but may relay them (gateways) to other nodes it gets connected to (i.e. the ones that are ON). This *PERM* value is used for routing which can be done by two routing protocols dedicated to this network, namely PERM and PERMUS protocols[8].

Routing protocols in Vint Cerf's DTN can be broadly classified (according to their tendency to make replicas) into two sets namely flooding (or replication) and forwarding based protocols. Protocols belonging to the flooding based set believe in making numerous copies of a message in a bid to increase its delivery probability. Some of them are Epidemic Routing [9], Credit Based Routing and Spraying[10,11], Spray and Wait[12], Spray and Focus[12], Practical routing [13], Conditional shortest path routing [14] etc. The family of forwarding based protocols consists of schemes which mostly use network oracles. Some of them are Two hop relay [15], Utility based routing [16], Mobispace [17] and Seek and Focus[18].

As these networks work in regions that have low and intermittent supply of energy we need to think of ways to decrease the amount of energy needed for transmission especially in sensor networks. One such method is data compression wherein the size of data to be transmitted is reduced thereby reducing the total energy required for its transmission. In this algorithm[19], focus is on energy savings as the primary metric instead. Another paper,[20] introduces a continuous-time Markov framework to model the message dissemination in DTN. Based on this framework, they formulate the optimization problem of opportunistic forwarding, with the constraint of energy consumed by the message delivery for both two-hop and epidemic forwarding. Then, based on the solution of the optimization problem, they design different kinds of forwarding policies such as static and dynamic policies. Among these policies, it is found that the threshold dynamic policy is optimal for both two-hop and epidemic forwarding. Another method is the Power Saving Management (PSM) [21]. PSM mode is as follows: Specifically, a node transmitting or receiving a DTO (Data Transfer Object) is in the transmitting or receiving state. When the node finishes any of these actions, it switches to a PSM mode. The PSM mode consists of switching between two wireless interface states:

- sleeping state: a node that is not transmitting or receiving packets, and thus remains in the sleeping state during an interval of time equal to Tsleep.
- search state: a node is in the idle state during an interval of time equal to Tsrch. While the node is in the idle state, the node switches periodically (i.e, beacon interval Tbc) to the transmitting state in order to send a beacon and then returns to the idle state.

[22] introduces a strategy to handle this for epidemic routing. The algorithm is as follows: A node that has received a copy of the message and is not its destination is referred to as an infective; a (non-destination) node that has not yet received a copy of the message is called a susceptible. A message is transmitted if the infective (transmitter) and susceptible (receiver) have at least T and r units of reserve energy, respectively. Transmission of the message between a pair of nodes consumes T units of available energy in the transmitter and r units in the receiver. If the infective (transmitter) and susceptible (receiver) have at least T and r units of reserve energy, respectively only then does a message transfer occurs. But the values of T and r could be too strict for a practical scenario. A new architecture,[23], uses throwboxes to combat loss of energy. Throwboxes are inexpensive, battery-powered, stationary nodes with radios and storage. When two nodes pass by the same location at different times, the throwbox acts as a router, creating a new contact opportunity. Even a small number of throwboxes can significantly increase the delivery rate found in a DTN. The throwbox employs an approximate heuristic for solving the NP-Hard problem of meeting an average power constraint while maximizing the number of bytes transferred by the throwbox. However establishment of throwboxes might not be possible in all networks. They will also add up to the total cost of installation and maintenance and consume additional energy however less it may be. Energy Conservation related work in HoP-DTN and Postbox DTN have not yet been done as to the best of our knowledge.

3. Proposed Approach

Before explaining the proposed scheme, let us discuss the Classical Postbox Model.

3.1. The Classical Postbox model

This model uses a one hop routing protocol which follows the post-office scenario. This DTN architecture involves a few persistent nodes which are always available i.e. no connection initiation action is required to instantiate. An always-on connection such as a modem would be an example of it. These persistent contacts are always up and have a huge buffer. Every other node within this cluster has to have a direct contact with the central persistent node at some time or the other. The postbox routing protocol in such a case is that if a node wants to send a message to some other node, it first sends the message to the central node with which it has a direct contact. If the receiver of the message is up simultaneously then the message is not stored in the central nodes buffer and is transferred to the receiver node. In such a transmission there is no use of message replication as the original message is only sent to the receiver. Another condition may occur that when the sender is up and wants to send its message to some destined receiver via the central persistent node. If the receiver node does not have immediate connection with the central persistent node i.e. the receiver node is down/disconnected then the message from the sender node is forwarded to the centrally active node and is stored in the central nodes buffer maintain a time stamp along with its message identification which generates the address of the receiver. Whenever the destined receiver node is up then it connects automatically with the central active node and receives the message destined for it. In this protocol, message duplication is greatly reduced as the original message is only transferred, so the chance of receiving faulty message is greatly reduced. The overhead involved both in message duplication and multiple hop

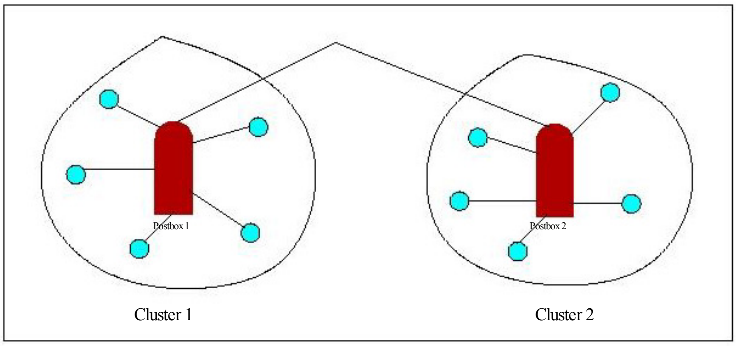

Figure 1. A general diagrammatic illustration of the classical Postbox-DTN

counts gets minimal as it is seen that the number of message hops can be a maximum of one. This scheme tries to fulfill the following objectives:

1. Achieves significantly lesser transmissions than epidemic and other flooding-based routing schemes, under all conditions.

2. Generates low belligerency, especially under high traffic loads.

3. Achieves a delivery delay that is better than existing single and multiple copy schemes.

4. Is scalable, that is, maintains the above performance behavior despite modifications made in network size or node density.

5. Is clear in understanding and requires as little knowledge about the network as possible in order to facilitate implementation.

In providing all of the above, it misses one crucial point that of energy consumption. As the large server like postbox remains up at all times, it consumes a huge amount of energy. This is where our new approach tries to improve.

3.2. ECOP: The Energy Conserving Postbox DTN Model

In our proposed model, instead of a single large Postbox in each cluster, there will be a group of Postboxes (known as Energy Conserving Postboxes i.e. ECOPs) interconnected with each other. These nodes will have scheduled contacts with each other as well as a definite time for being ON/UP i.e. they will be implementing schedule power ON/OFF and time share the responsibility. To all other nodes in the network they will appear as a single Postbox hence all their working and splitting of responsibility is a black box method.

Let us explain our model in detail: We split the original Postbox into 3 smaller Postboxes or ECOPs all of equal size. Let us number them as ECOP1, ECOP2 and ECOP3. ECOP1 is ON for 1hour. Then ECOP2 is switched ON for the last 20minutes of ECOP1 being ON (i.e. when ECOP1 has been ON for 40minutes). If network traffic demand surpasses the threshold traffic value of τ i.e.,

$\sum T_l + b_{pb} >= \tau$ then,

ECOP1 as well as ECOP2 stays ON for another hour.

If network traffic not heavy ($\sum T_l + b_{pb} < \tau$) then copy all data of ECOP1 to ECOP2. Let ECOP1 go to sleep and only ECOP2 keeps functioning. By doing this we reduce the wear and tear and overheating of the same Postbox. Hence fairness is ensued.

Then ECOP3 is switched ON during the last 20 minutes of ECOP2 being ON (or ECOP2 and ECOP3 being ON together). This process goes on in a Round Robin fashion.

For routing it follows the Postbox Based Routing Protocol as discussed in[3].

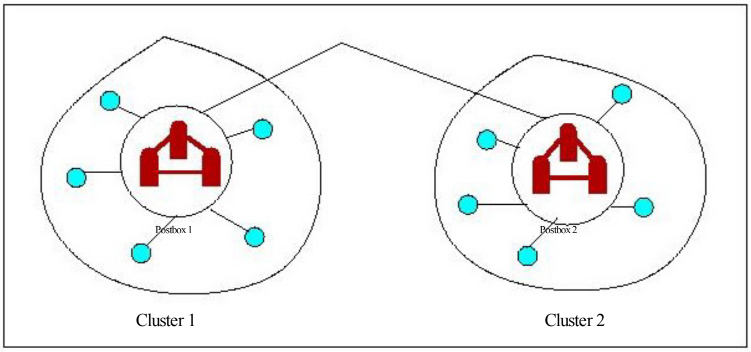

Figure 2. A general diagrammatic illustration of Energy Conserving Postbox-DTN

3.3. The Algorithm

The symbols used in the algorithms have the following meaning.

b_i = Buffer of sender node. *connec* = Connection between two nodes.

data = Message to be forwarded. b_{pb} = Buffer of ECOP.

$connec_i$ = Connection of node *i* to the ECOP. $connec_j$ = Connection of node *j* to the ECOP.

Algorithm 1: AtEachNode

for *node i* **do**
  if $b_i \neq$ *empty* **then**
    if *connec* = *ON* **then**
      send data to cluster Postbox
    else if *data to be sent ready but connec* = *OFF* **then**
      $b_i = b_i +$ data

Algorithm 2: AtEachECOP

for *every node i in the cluster network* **do**
  if $connec_i$ = *ON and data to be sent= Enable* **then**
    accept data from node *i* with destination node *j*
  if $connec_j$ = *ON* **then**
    send data to node *j*
  else
    wait for $connec_j$ to be *ON* $b_{pb} = b_{pb} + 1$
if *Runtime of ECOP* = 60 **then**
  if $\sum T_l + b_{pb} >= \tau$ **then**
    ECOP remains ON for another 60 minutes.
  else
    Transfer all data to next ECOP and goto sleep for another 60 minutes.

4. Performance Analysis

4.1. Mathematical Analysis

4.1.1. Total Hop Count

For intra cluster communication :

For n nodes in a network, each node can send m messages. Total hop count of *one* node sending *one* message to *one* node in the cluster = 1.

$\therefore$ Total hop count of *one* node sending *one* message to n nodes within the cluster= $1 \times (n-1)$

Total hop count of *one* node sending *one* message to x nodes within the cluster= $1 \times x$

Total hop count of n nodes sending m messages to x nodes = $x \times m$

Total hop count of n nodes sending m messages to all nodes = $x \times (n-1)$

For inter cluster communication :

Hop counts required to send a message from *one* in home cluster to a node in a different cluster= 2. $\therefore$ Total hop count of *one* node sending *one* message to k nodes in a foreign cluster= $2 \times k$

Total hop count of n nodes sending m messages to k nodes in a foreign cluster = $2 \times k \times m$

4.1.2. Total Delay

Time taken for sending a message from source to postbox= t_{spb}

Time taken for sending a message from postbox to destination within the same cluster= t_{pbd}

Total time taken for a message to reach destination= $t_{spb} + t_{pbd}$

Time taken to send a message to all nodes= $(n-1) \times (t_{spb} + t_{pbd})$

Time taken to send m messages to all nodes within the cluster= $m \times (n-1)(t_{spb} + t_{pbd})$

4.1.3. Buffer Size

For a node i, buffer size is b_i.

For all n nodes, if buffer size is same then total buffer size of all nodes within a cluster= $n \times b_i$

Buffer size of ECOP1= b_{pb}

As all ECOPs are of equal sizes, total size of all ECOPs together= $3 \times b_{pb}$

$\therefore (3 \times b_{pb})$ must be $> = n \times b_i$.

4.2. Simulation Analysis

As no other work has been done regarding energy conservation in Postbox DTN, we can only compare our proposed methodology with the existing classical Postbox model and show how it improves its energy conservation. For simulation purposes, we have considered that the classical Postbox a buffer capacity of 300 units and the ECOPs are of size 100 each. Energy consumption has been considered at 0.01 units per unit size of the Postboxes. We are eliminating the energy consumption due to other peripheral causes as they would remain the same in both cases. There are a total of 30 nodes in a cluster who keep going ON/OFF on a random basis. We have done the simulations using the C programming language with a time step up of 1 minute.

4.2.1. Energy Consumption

Fig. 3 gives the comparison plot between ECOP and Classical Postbox performance on the amount of energy consumed with varying amount of Time, keeping the Message Traffic from all nodes at a constant of 50. Fig. 4 shows the same but with Message Traffic at a constant of 150. From both the plots it is very evident that ECOPs consumes a considerably less amount of energy as compared to the classical Postbox method. In fact we can deduce from the data that the Classical Postbox Model consumes on an average 158.14% more energy than our proposed ECOP Model.

4.2.2. Delivery Capability

Fig. 5 gives the comparison plot between ECOP and Classical Postbox performance on the number of messages delivered with varying Message Traffic, keeping the Time at a constant of 20 minutes. Fig. 6 shows the plot of

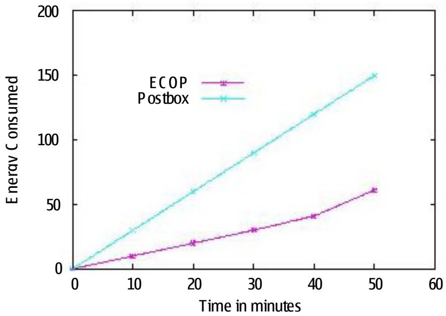

Figure 3. Energy Consumption with respect to Time (Message Traffic constant at 50)

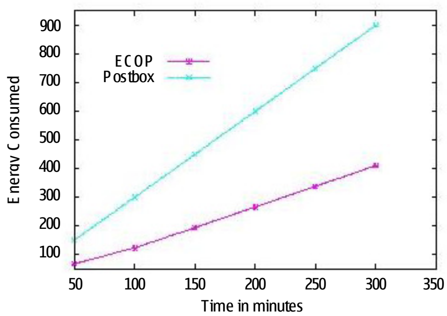

Figure 4. Energy Consumption with respect to Time (Message Traffic constant at 150)

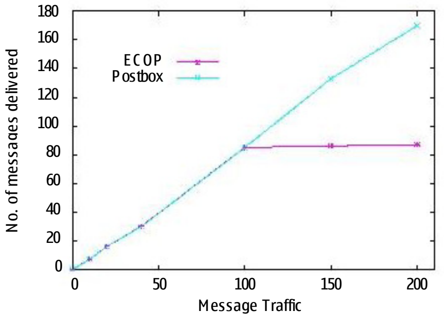

Figure 5. Delivery capability (Time constant at 20 minutes)

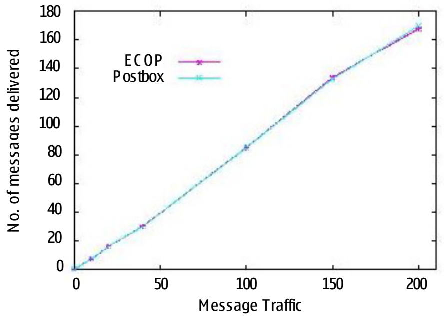

Figure 6. Delivery capability (Time constant at 200 minutes)

delivery capability between the two with Time constant at 200 minutes. We see that if within a short span of time during network initialization (within the first 40 minutes, see Fig. 5), if a huge message traffic starts pouring in, then the performance of ECOP tends to degrade. This is due to the fact that the message traffic then exceeds the buffer size of the lone ECOP. However from Fig. 6 we see that if the system is running for a longer stretch of time (here 200) when other ECOPs are scheduled switched ON, then the delivery capability is the same as that of the Classical Postbox. This is due to the fact that for all other nodes in the system the Postbox remains the same and the division of Postboxes into ECOPs is a black box process.

5. Conclusion

The DTN was a blessing to heterogeneous challenged networks like those of sensor networks which kept going UP and DOWN in an unpredictable manner. Postbox DTN was introduced for quite such networks, allowing nodes to be ON and OFF as and when they do and not worry about the routing of their messages. They just need to send the message to their Postbox and the rest was taken care of by the Postbox. This method though consumed a lot of energy as the Postbox needed to be ON at all times. Also a single point of failure at the Postbox would bring down the whole network. This paper works on this particular area and modifies the classical model by splitting one large Postbox into 3 smaller ECOPs who time share the responsibility. Simulation results show our presumption to be correct and it is seen that the Classical Postbox Model consumes on an average 158.14% more energy than our proposed ECOP Model.

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